Integrated Visible Photonics for Trapped-Ion Quantum Computing

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***Abstract*- A scalable trapped-ion-based quantum-computing architecture requires the capability to optically address individual ions at several wavelengths. We demonstrate a dual-layered silicon nitride photonic platform for integration into planar ion traps designed for trapped-ion control in a 400 to 1100 nm wavelength range.**

I. Introduction

Trapped-ion qubits, with their long coherence times, strong coulomb interactions, and optical addressability, hold great promise for implementation of practical quantum information processers. However, preparing, manipulating and reading out the ions' quantum state requires optical probing across a number of wavelengths that span the visible and near IR spectrum. Further, a scalable trap architecture requires many (thousands to millions of) ions in close proximity to one another. These ions must be individually addressed and the fluorescence of each individually detected, making the use free space optics infeasible [1].

Integrated photonics in the visible and near IR provides a scalable platform in which the optical beams can be routed beneath a planar ion trap array and directed out-of-plane to address the ions of interest. Silicon-nitride photonic integrated circuits (PICs) offer an appealing system for trap applications. Qualities such as broad transparency at the wavelengths of interest (405-1092 nm for the Sr^+ and Ca^+ ion system), good material stability, and high optical confinement enable compact optical designs with tight bend radii. In this study we report on optical measurements of a dual-layer low-pressure chemical vapor deposition (LPCVD) stoichiometric silicon nitride (Si_3N_4) PIC fabricated in MIT Lincoln Laboratory's 200-mm-wafer, 90-nm-resolution CMOS-capable Microelectronics Lab. The platform features silicon-dioxide cladding, and two layers of 100-nm thick silicon nitride separated by a 2-µm oxide gap. The platform is similar in structure to those demonstrated by others for 1550 nm operation [2], but here tailored for the visible and IR. To evaluate chip performance we designed a variety of test structures including paperclips to measure optical losses, in-plane and out-of-plane waveguide crossings, 3 dB couplers, power taps, and focusing vertical grating couplers designed to project the light out of the chip and onto the desired ions located~50µm above the chip surface.

II. Results

Device fabrication begins with a 5-µm bottom-clad PECVD oxide that is annealed in nitrogen for densification and hydrogen desorption. We then deposit a100-nm LPCVD Si_3N_4 waveguide layer. Waveguide patterning is accomplished using 193-nm DUV lithography. An additional lithography step and partial depth etch is used for fabrication of the vertical grating couplers. A 2-µm-thick oxide layer caps the first nitride layer and gratings, and is then annealed and polished to remove residual topography prior to deposition of the second nitride layer. The second nitride layer waveguides are patterned similarly to the first, and a final 2-µm-thick layer of PECVD oxide is deposited as the top cladding and is once again annealed. The structure is completed with a deep oxide and silicon etch to provide a smooth oxide facet, and clearance for fiber positioning for edge input coupling.

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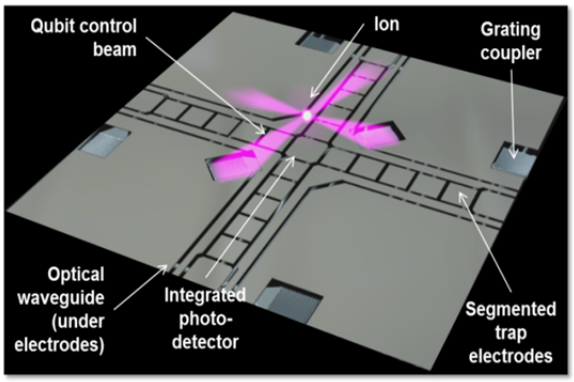

Fig. 1a. Photonic integration with a planar ion trap.

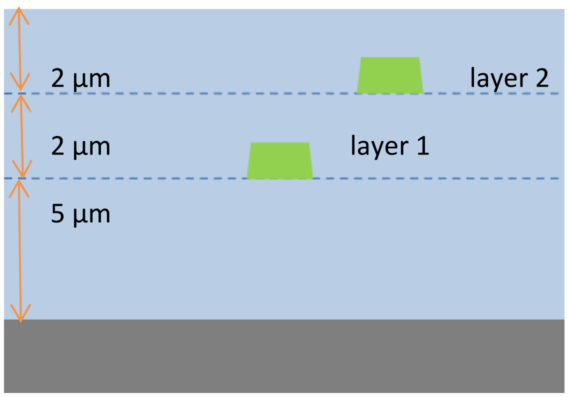

Fig. 1b. Si_3N_4 waveguide cross-section

Transmission losses were measured using paperclip test structures of 5 different lengths. The paperclips featured a variety of widths (250, 500, and 1100 nm) designed for single mode operation in blue (λ=405-427 nm), red (634 nm), and IR (1092 nm) wavelengths, respectively. Bend radii were chosen to ensure low loss. Input light was provided by 405, 423,427, 634, and 1092 nm wavelength diode lasers, and focused onto the etched input facet of the PIC selecting for either bottom or top nitride waveguide layers. Output light was measured on a Thorlabs power head.

III. Discussion

As shown in Fig 2, we see very low loss (<0.2 dB/cm) throughout the red and near-IR but a large increase in loss (>10 dB/cm) in the blue. We note that the losses in the two nitride layers are very

similar to one another with the loss in Layer 1 being slightly lower, perhaps due to the increased thermal cycling. We also note that the TM losses are somewhat lower than the TE losses, likely due to the lower confinement in the nitride as well as the lower exposure to scattering induced by sidewall roughness. TE losses in the blue were only taken at 427nm due to challenges in coupling at shorter wavelengths. We note that the dependence of loss on wavelength in the red and near IR is consistent with scattering loss being the dominant loss mechanism. The extreme change in loss over such a narrow wavelength range in the blue, however, cannot be accounted for with scattering loss and strongly suggests material absorption is the dominant form of loss in this region. Measured performance of additional optical devices needed for ion control will be discussed during the conference presentation.

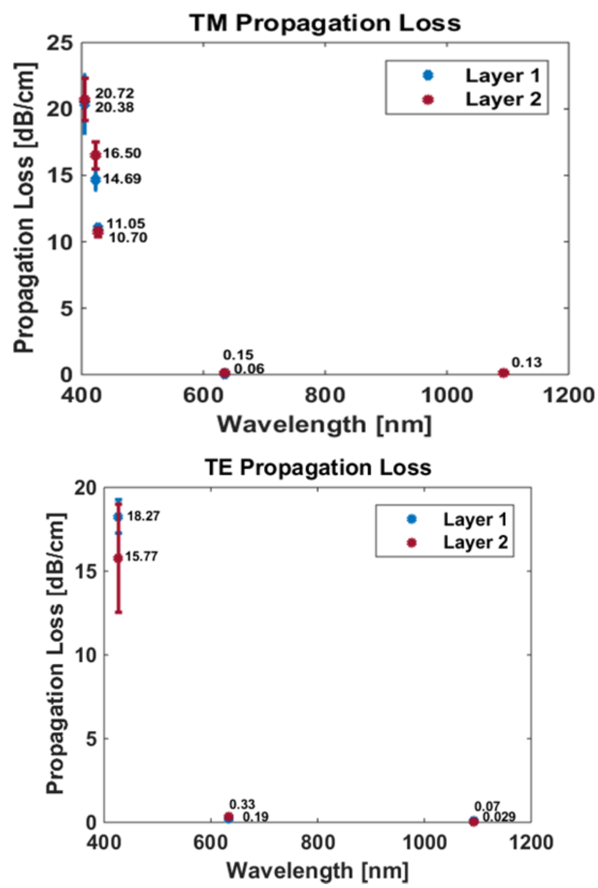

Fig. 2. TM and TE polarized optical loss measured in 100-nm-thick silicon nitride waveguides in layer 1 and 2.

References

[1] K. Mehta et. al. "Integrated optical addressing of an ion qubit", Nature Nanotechnology, 10.1038 (2016).

[2] K. Shang et. al. “Low-loss compact multilayer silicon nitride platform for 3D photonic integrated circuits”, Opt. Express 23(16), 241398 (2015)